

XFROG Characterization of a 10 GHz Colliding-Pulse Mode-Locked Laser

N. K. Fontaine, C. Ji, R. G. Broeke, J. Cao, S. W. Seo, S. J. B. Yoo

Department of Electrical and Computer Engineering, University of California, Davis, CA 95616, USA

Email: yoo@ece.ucdavis.edu

K.Y. Liou, J. R. Lothian, S. Vatanapradit, S.N.G. Chu, B. Patel,

W.S. Hobson, W. T. Tsang

Multiplex, Inc., 5000 Hadley Road, South Plainfield, New Jersey 07080 USA

Abstract: We present XFROG characterization of a 10 GHz colliding-pulse mode-locked laser on InP under hybrid modelocking. Pulse shape and chirp were extracted directly from the XFROG traces for power level as low as -10 dBm.

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Monolithic semiconductor mode-locked lasers operating at 10 GHz are attractive ultra-compact light sources for 10 Gb/s communications and integrated photonic micro-system applications [1]. Previously, we have reported [2] the fabrication and characterization of a 10 GHz buried heterostructure (BH) colliding-pulse mode-locked (CPM) laser, with active-passive integrated waveguides. While the mode-locked laser output pulse is typically characterized through the standard SHG based autocorrelation approach, frequency-resolved optical gating (FROG) [3] is a powerful technique that precisely determines the pulse shape and phase information of a short pulse, which can not be obtained through autocorrelation. In this paper, we applied cross-correlation frequency-resolved optical gating (XFROG) to fully characterize the 10 GHz CPM laser output for the first time, and demonstrated its application for pulse compression.

Fig. 1 shows the experimental setup. The CPM laser operated in the hybrid mode locking (HML) regime with DC current applied to the two gain sections, reverse biasing DC voltage applied to the saturable absorber (SA), and RF-clock modulation signal applied to the SA through a microwave probe. The laser output, collected by lensed fibers, was routed to an optical spectrum analyzer (OSA) and a RF spectrum analyzer for optical and RF spectral analyses, and the XFROG setup for pulse shape and chirp characterization. The 10 GHz fiber mode-locked laser provided the 2.5 psec gate signal for XFROG, triggered with the RF clock.

For this study, we chose a 3 μm -wide CPM laser with two 750 μm -long gain sections, which sandwich a central 35 μm -wide saturable absorber. Passive waveguides symmetrically extended the cavity length to 8600 μm . The resulting passive mode-locking frequency is 9.835 GHz. The mode-locking behavior was a strong function of the DC and RF biasing conditions. With 19 dBm RF modulation at 9.835 GHz applied to the SA, the optical spectrum changes dramatically with DC biasing conditions. Fig. 2(a) shows the symmetrical optical spectrum optimized for a short temporal pulse ('short') under DC biasing of 89 mA gain current and -7.5 V SA biasing. In Fig. 2(b) the pulse was optimized for a wide spectrum ('wide') and was strongly asymmetric with 156.4 mA gain current and -4.48 V SA biasing. With the gate signal at 10 dBm, the XFROG obtained a clean trace with fiber coupled CPM output as low as -10 dBm. The retrieved XFROG traces match the measured XFROG traces with residual error <0.006 . This implies that our XFROG setup has sufficient sensitivity for direct characterization of the CPM laser output without additional EDFA amplification, which can introduce unintended chirping and pulse reshaping.

Fig. 3(a) and Fig. 4(a) show the XFROG traces for the 'short' and 'wide' DC biasing conditions. Fig. 3(b) and Fig. 4(b) show the corresponding retrieved pulse shapes and wavelength chirp. For the 'short' case, the XFROG extracted pulse width was 5.1 psec, with a time-bandwidth product (TBP) of 0.6. A small amount of chirp can be observed in Fig. 3(b) and is mostly linear. For the 'wide' case, the pulse width was 33 ps (TBP 3.76), and as observed in Fig. 4(b) the pulse exhibited much stronger chirp. From Fig. 3(b) and Fig. 4(b) we note that the actual pulses shape can deviate from the ideal Gaussian or sech^2 forms, which can not be detected through the direct autocorrelation approach. Based on the amount of chirp characterized with XFROG from Fig. 4 for the 'wide' case, pulse compression by linear dispersion compensation was

performed by adding 500 meters of SMF fiber to the laser output. Fig. 5(a) and (b) show the resulting XFROG trace and extracted pulse, with a pulse width of 1.8 psec. Simulation shows that the ringing in the pulse in Fig. 5(b) is a result of higher order uncompensated chirp. With removal of the higher order chirp the expected pulse width is only 1.3 psec.

In conclusion, we have characterized using XFROG a 10 GHz CPM laser under HML. The XFROG setup is sensitive to average power levels as low as -10 dBm (pulse energy 10 fJ), which allowed direct characterization of the CPM laser output, without additional EDFA based amplification. We showed that with XFROG quantitative pulse shape and chirp characteristics of the CPM laser can be extracted, allowing for precise dispersion compensation and pulse compression.

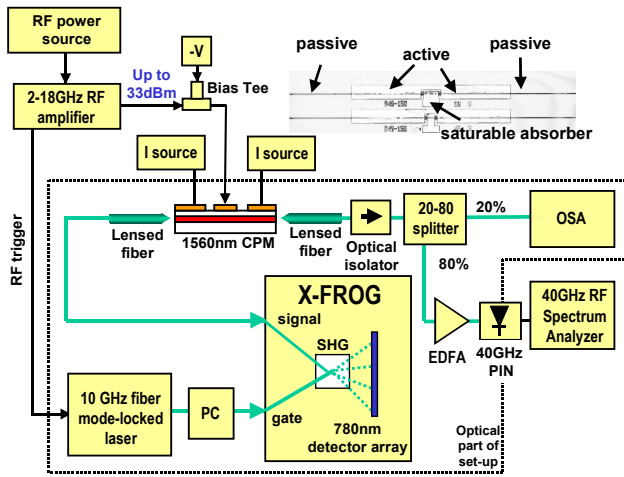


Fig. 1 XFROG experimental setup (inset showing schematic diagram of the CPM laser).

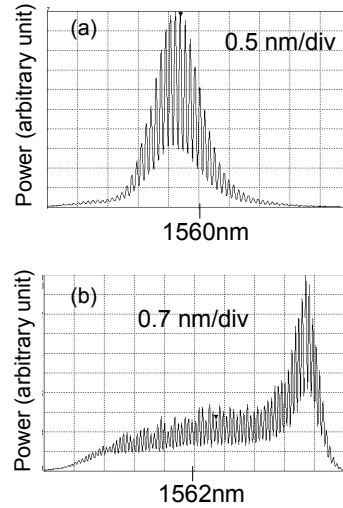


Fig. 2. Optical spectra under HML with different DC biasing conditions. (a) 'short' pulse (b) 'wide' spectrum

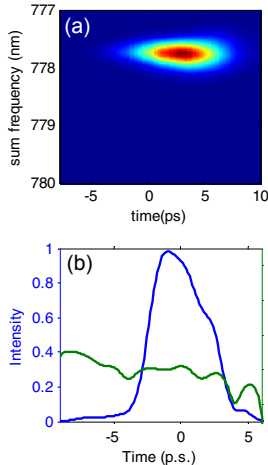


Fig. 3(a) XFROG trace and (b) extracted 'short' pulse shape and chirp vs. time for the condition corresponding to Fig 2(a)

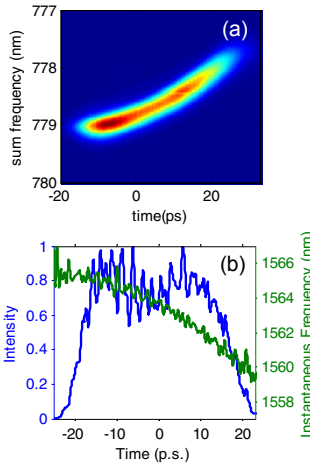


Fig. 4(a) XFROG trace and (b) extracted 'wide' pulse shape and chirp vs. time for the condition corresponding to Fig 2(b).

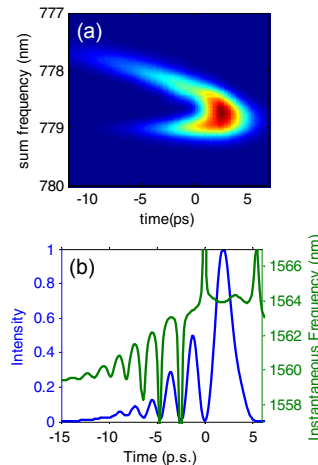


Fig.5(a)) XFROG trace and (b) extracted compressed 'wide' pulse shape and chirp. Ringing due to higher order chirp.

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